Performance analysis of UAV assisted Wireless Powered Communication system over Rician fading channel

A thesis submitted in partial fulfillment of the requirements for the award of the degree of

B.Tech

in

Electronics and Communication Engineering

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BONAFIDE CERTIFICATE

This is to certify that the project titled **Performance analysis of UAV assisted Wireless Powered Communication system over Rician fading channel** is a bonafide record of the work done by

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in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics and Communication Engineering** of the **NATIONAL INSTITUTE OF TECHNOLOGY, TIRUCHIRAPPALLI**, during the year 2020-21.

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Internal Examiner	**External Examiner**

ABSTRACT

In modern wireless powered communication networks like Internet of Things(IOT), the usage of UAV as a cooperative node is seen as a promising technique. In this work, we analyze the performance of a single hop UAV system which consists of energy harvesting enabled nodes, with UAV as the destination. The UAV harvests energy using the signal received from user equipment or the node via wireless power transfer (WPT) link and information transfer takes place from the UAV to user equipment via wireless information transfer (WIT) link. For the proposed system, we derive the outage probability, Bit error rate, Ergodic capacity and throughput,including closed form expressions in terms of channel parameters like time splitting constant(alpha),SNR etc for Rician fading channel.Also derived the above mentioned parameters for other fading channels like Rayleigh, Nakagami-m, Weibull to compare the results in order to find which model is more suitable for this system.Also, find the optimum value of alpha for which maximum output can be obtained for the aforementioned system. Finally, the numerical simulation results are provided to show the system performance.

Keywords : Unmanned aerial vehicle(UAV), wireless power transfer(WPT), wireless information transfer(WIT),Outage probability,Bit error rate, Ergodic capacity,Maximum throughput

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to the following people for guiding us through this course and without whom this project and the results achieved from it would not have reached completion.

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CHAPTER 1
INTRODUCTION

In recent times ,low-power wireless application networks such as the Internet of Things (IoT's) and Wireless Sensor Networks (WSNs) have attracted a great deal of interest due to massive connectivity and thus leading to development of numerous applications based on these domains.
With the large-scale deployment of 5G and the continuous evolution of mobile communication systems, most energy-consuming applications, including video streaming services, AR/VR transmissions, and much more, now run on mobile devices powered by batteries.A growing number of people worldwide are now also using small Internet of Things (IoT) devices, such as temperature PM2.5 sensors, smart watches, fitness trackers and other devices, with an average density of one device per square meter.
These small devices can only be equipped with batteries that have low capacity and thus drain much faster.As these networks are powered via these rechargeable batteries and recharging or replacing these batteries frequently are not an optimal solution, Energy Harvesting technique is used.

1.1 Energy Harvesting (EH)

Energy harvesting (also known as energy scavenging) is the conversion of ambient energy present (thermal, wind, solar, Radio Frequency) in the environment into electrical energy for use in powering autonomous electronic devices or circuits.
RF-based EH technique provides a ubiquitous and sustainable solution to the user even at a longer distance from the power source.
This is because RF signals carries **both energy and information together**.
Steps involved in Energy Harvesting:
1) Accumulating Energy
2)Storage of power
3)Usage of power

Generally energy harvested is stored in Super capacitors or batteries . Compared to batteries, super capacitors have virtually unlimited charge-discharge cycles and can therefore operate forever enabling a maintenance-free operation in IoT and wireless sensor devices. Thus, super capacitors are preferred over batteries.

RF based Energy Harvesting techniques

Currently,in RF-based energy harvesting techniques, these are the two key emerging methods :
1)Simultaneous wireless information and power transfer (SWIPT)
2)Wireless powered communication (WPC)

SWIPT:
This technique involves utilizing the same RF signal for both energy harvesting and information decoding at the energy constrained node. Thus it is an **spectrum efficient** method.

WPC:
In WPC technique, both wireless power transfer (WPT) and information transfer (WIT) are performed separately such that a hybrid access point (HAP) broadcast energy in the downlink and receives information in the uplink.

UAV

Unmanned aerial vehicles (UAVs) (or Drones) are expected to be widely deployed in the future for enabling a proliferation of applications ranging from aerial delivery to surveillance and monitoring, disaster rescue, and remote sensing.Among others, dispatching UAVs to harvest sensing-data from distributed sensor nodes (SNs) is anticipated to be a promising technology for realizing the future Internet of Things (IoT).Due to its various applications, we have considered a system consisting of UAV for our analysis.

Why Rician fading channel ?

Widely adopted model for UAV application is the Rician fading model that comprises a deterministic LoS component and a random multipath component due to reflection,scattering, and diffraction by the ground obstacles . This model is suitable for urban/suburban areas with the UAV at a sufficiently high altitude with less shadowing but non-negligible smallscale fading. The Rician factor,which is affected by the communication band (L/C band), surrounding environment, and the UAV-ground elevation angle.

SYSTEM MODEL

After deriving and understanding the mathematics involved for a generic system,we are considering the below system for analysis :-

A point to point system with a sender and receiver , where the receiver is an **UAV**.

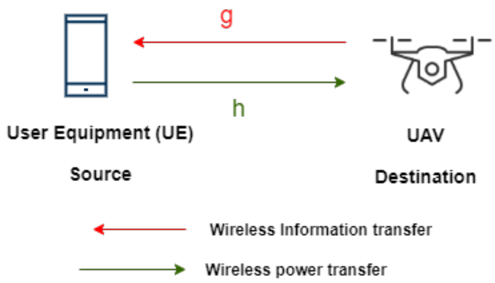

Figure 1.1: System model

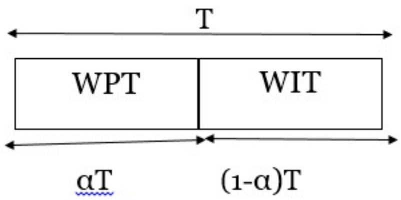

Figure 1.2: Time slot

Phase-1:WPT
Energy harvested at destination

$$EH = \alpha T \eta P_s |h|^2 \tag{1.1}$$

Phase-2: WIT
Received signal at source

$$Y_s = \sqrt{P_R} g X_e + n_e \tag{1.2}$$

Signal to Noise Ratio is given as

$$\gamma_{DS} = \alpha\eta \frac{P_s |h|^2 |g|^2}{\sigma^2 (1-\alpha)} \tag{1.3}$$

$$\gamma_{DS} = \phi|h|^2|g|^2 \tag{1.4}$$

where

$$\phi = \alpha\eta\frac{P_s}{\sigma^2(1-\alpha)} \tag{1.5}$$

This derivation of energy harvested and received signal remains same for all fading channels considered for this system.

Below are the various distributions considered for this syetem.For each system Outage probability, Bit error rate , Ergodic Capacity and Throuhput is computed and further compared in order to obtain the most suitable fadicng channel for the system.

CHAPTER 2
DISTRIBUTIONS

2.1 RICIAN DISTRIBUTION

Rician fading or Ricean fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal or some strong reflection signals, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution.

Outage Probability

Outage Probability is defined as the probability that information rate is less than the required threshold information rate.

Phase-1:WPT

Energy harvested at destination

$$EH = \alpha T \eta P_s |h|^2 \tag{2.1}$$

Phase-2: WIT

Received signal at source

$$Y_s = \sqrt{P_R} g X_e + n_e \tag{2.2}$$

Signal to Noise Ratio is given as

$$\gamma_{DS} = \alpha\eta \frac{P_s |h|^2 |g|^2}{\sigma^2 (1-\alpha)} \tag{2.3}$$

$$\gamma_{DS} = \phi |h|^2 |g|^2 \tag{2.4}$$

where

$$\phi = \alpha\eta\frac{P_s}{\sigma^2(1-\alpha)} \tag{2.5}$$

$$P_{OutageDS} = Pr(\gamma_{ds} < \gamma_{th}) \tag{2.6}$$

$$= Pr(\phi|h|^2|g|^2 < \gamma_{th}) \tag{2.7}$$

$$= Pr\left(y < \frac{\gamma_{th}}{\phi x}\right) \tag{2.8}$$

where $|h|^2 = x$, $|g|^2 = y$

$$= F_y(\frac{\gamma_{th}}{\phi x}) \tag{2.9}$$

Here The PDF is as follows

$$f_\gamma(\gamma) = \frac{1}{(e)^k}\sum_{n=0}^{\infty}\frac{k^n}{(n!)^2}(a)^{n+1}(\gamma)^n exp(-a\gamma) \tag{2.10}$$

The CDF is as follows

$$F_y(\gamma) = \frac{1}{(e)^k}\sum_{n=0}^{\infty}\frac{k^n}{(n!)^2}\gamma_{inc}(n+1, a\gamma) \tag{2.11}$$

According to the definition of distribution function
now integrate from zero to infinity

$$P_{OutageDS} = \int_0^\infty {}_{Fy}(\frac{\gamma_{th}}{\phi x})f_x(x)dx \tag{2.12}$$

$$P_{OutageDS} = exp(-k_{ds}-k_{sd})\sum_{n=0}^{\infty}\sum_{m=0}^{\infty}\frac{(k_{ds})^m(k_{sd})^n}{(m!n!)^2}(a_{sd})^{n+1}\int_0^\infty x^n e^{-a_{sd}x}\gamma_{inc}(m+1, a_{ds}\frac{(\gamma)_{th}}{\phi x})dx \tag{2.13}$$

From table of integrals we have the final equation of outage probability as follows

$$P_{Outage_{DS}} = exp(-k_{ds}-k_{sd})\sum_{n=0}^{\infty}\sum_{m=0}^{\infty}C_{m,n}G^{\,2\;1}_{\,1\;3}\left(\left.\begin{matrix}1\\ n+1, m+1, 0\end{matrix}\right|\frac{\gamma_{th}a_{ds}a_{sd}}{\phi}\right) \tag{2.14}$$

where

$$C_{m,n} = \frac{(k_{sd})^n(k_{ds})^m}{(m!n!)^2} \tag{2.15}$$

$$a_{ds} = \frac{(1+k_{ds})}{\Gamma_{ds}} \tag{2.16}$$

Outage Probability variations wrt channel parameters

- Variation with SNR
- Variation with Alpha

  Here, Alpha is the time splitting constant and it is restricted to lie between 0 to 1. Instead of infinite summation, m and n are restricted to the value 10,as for higher values the summation terms are negligible.

Plots for Outage probability

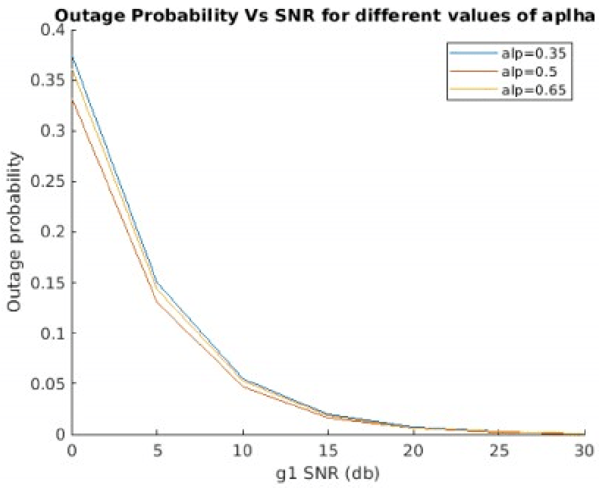

Figure 2.1: Outage Probability Vs SNR

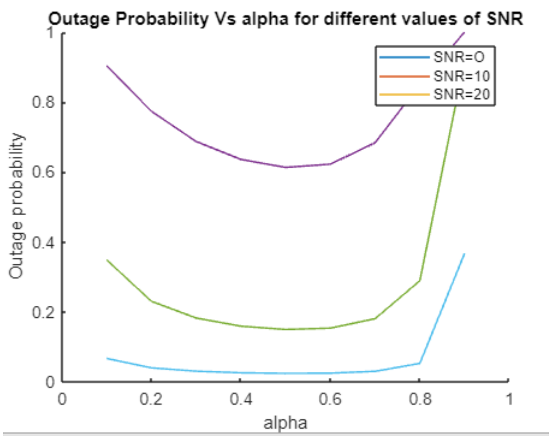

Figure 2.2: Outage probability Vs Alpha

Bit Error Rate

Bit error rate is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits.

$$AverageBitErrorRate = \frac{noofbitsinerror}{Totalnoofbitstransmitted} \tag{2.17}$$

BER for rician can be given by

$$BER = \frac{a}{2}\sqrt{\frac{b}{\pi}}\int_0^\infty \frac{e^{-b\gamma}}{\sqrt{\gamma}} F(\gamma)d\gamma \tag{2.18}$$

Here

$$F(\gamma) = exp(-k_{ds} - k_{sd})\sum_{n=0}^{\infty}\sum_{m=0}^{\infty} C_{m,n} G_{1\ 3}^{2\ 1}\left({}^{\quad\ 1}_{n+1,m+1,0} \middle| \frac{\gamma a_{ds} a_{sd}}{\phi} \right) \tag{2.19}$$

Converting exponential term to Meijer g function we have

$$e^{-b\gamma} = G_{0\ 1}^{1\ 0}\left({}^{-}_{0} | b\gamma \right) \tag{2.20}$$

Now by the formula of integration for two meijer g functions we have the final BER as follows

$$BER = z\frac{a}{2}\sqrt{\frac{b}{\pi}}\sum_{n=0}^{\infty}\sum_{m=0}^{\infty} C_{m,n}\frac{1}{\sqrt{b}} G_{2\ 3}^{2\ 2}\left({}^{\quad 1,0.5}_{n+1,m+1,0} \middle| \frac{a_{ds} a_{sd}}{\phi b} \right) \tag{2.21}$$

where

$$z = exp(-k_{ds} - k_{sd}) \tag{2.22}$$

$$C_{m,n} = \frac{(k_{sd})^n (k_{ds})^m}{(m!n!)^2} \tag{2.23}$$

Plot for Bit Error Rate(BER)

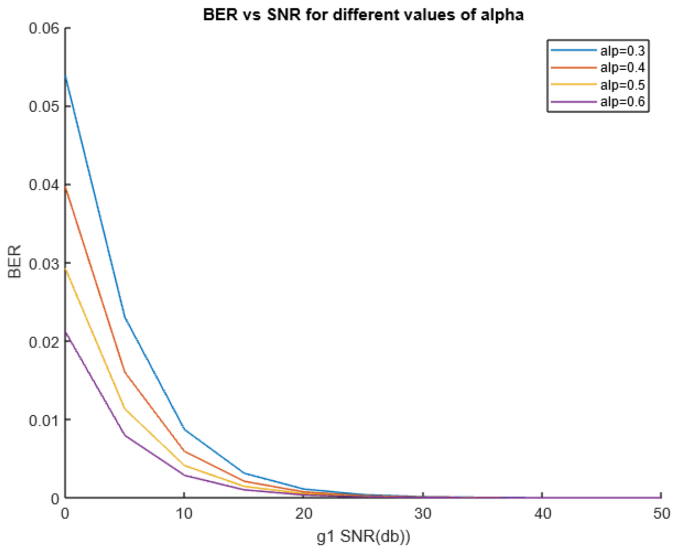

Figure 2.3: BER Vs SNR for different values of alpha

Ergodic Capacity

Ergodic capacity is the upper bound of the capacity on the statistics channel (i.e. time-varying channel). It can be evaluated by averaging the capacity is obtained at a particular time instance on a fading channel over an infinite time interval.

$$C_{erg} = E[log_2(1+\gamma)] \tag{2.24}$$

$$C_{erg} = \frac{1}{ln2}\int_0^{\infty} f_{\gamma}(\gamma) ln(1+\gamma) d\gamma \tag{2.25}$$

The final expression for Ergodic capacity is as follows

$$C_{erg} = \frac{z}{ln(2)} \sum_{n=0}^{\infty}\sum_{m=0}^{\infty} C_{m,n} G_{6\ 4}^{3\ 4}\left({}^{1,-n,-m,1,0,1}_{1,1,0,0} \middle| \frac{\phi}{a_{ds}a_{sd}} \right) \tag{2.26}$$

where

$$z = exp(-k_{ds} - k_{sd}) \tag{2.27}$$

$$C_{m,n} = \frac{(k_{sd})^n (k_{ds})^m}{(m!n!)^2} \tag{2.28}$$

$$a_{ds} = \frac{(1+k_{ds})}{\Gamma_{ds}} \tag{2.29}$$

Plots for Ergodic Capacity

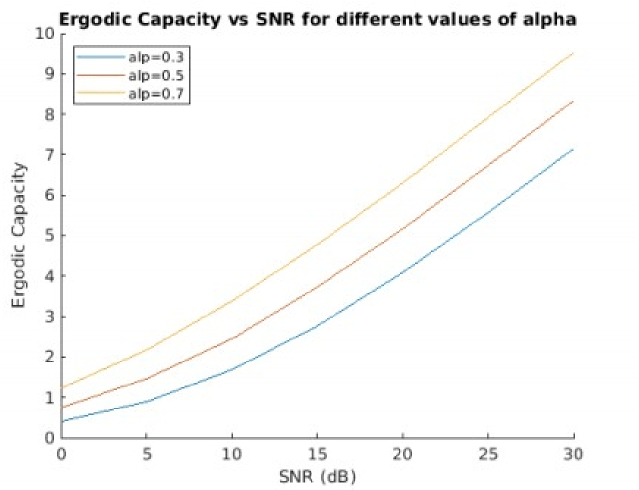

Figure 2.4: Ergodic Capacity Vs SNR for different values of alpha

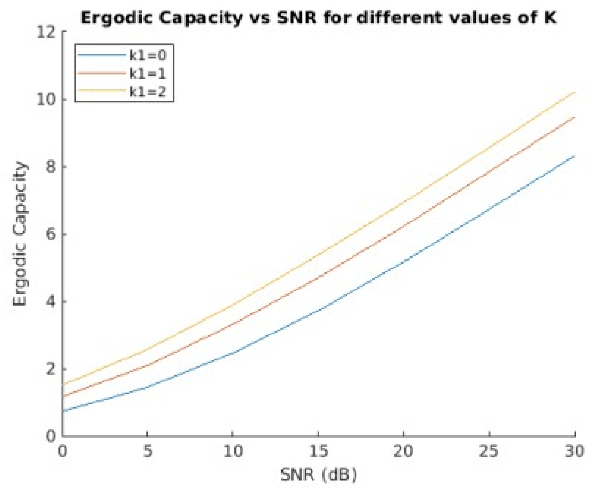

Figure 2.5: Ergodic Capacity Vs SNR for different values of k

THROUGHPUT

Throughput or network throughput is the rate of successful message delivery over a communication channel.

The expression for maximum throughput with respect to **outage probability** for rician distribution is as follows In general

$$Throughput = \frac{RT}{2}(1 - P_{outage}) \tag{2.30}$$

Where, R is Rate of Transmission
T is Transmission block time

$$Throughput = \frac{RT}{2}(1 - exp(-k_{ds} - k_{sd})\sum_{n=0}^{\infty}\sum_{m=0}^{\infty} C_{m,n} G_{1\,3}^{2\,1}\left(\left.\begin{matrix}1\\ n+1, m+1, 0\end{matrix}\right| \frac{\gamma_{th} a_{ds} a_{sd}}{\phi}\right)) \tag{2.31}$$

The expression for maximum throughput with respect **ergodic capacity** for rician distribution is as follows

$$Throughput = (1 - \alpha)Ergodiccapacity \tag{2.32}$$

$$Throughput = (1 - \alpha)\frac{z}{ln(2)}\sum_{n=0}^{\infty}\sum_{m=0}^{\infty} C_{m,n} G_{6\,4}^{3\,4}\left(\left.\begin{matrix}1, -n, -m, 1, 0, 1\\ 1, 1, 0, 0\end{matrix}\right| \frac{\phi}{a_{ds} a_{sd}}\right) \tag{2.33}$$

Plots for Maximum Throughput

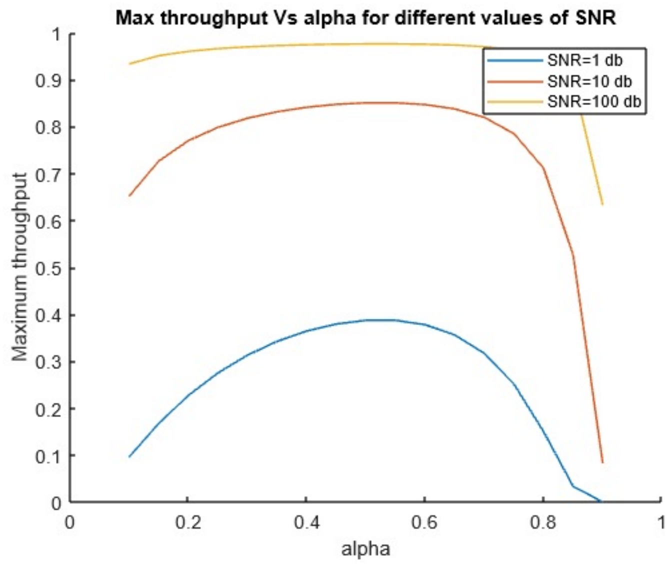

Figure 2.6: Maximum Throughput Vs alpha with respect to **outage probability** for different values of **SNR**(dB)

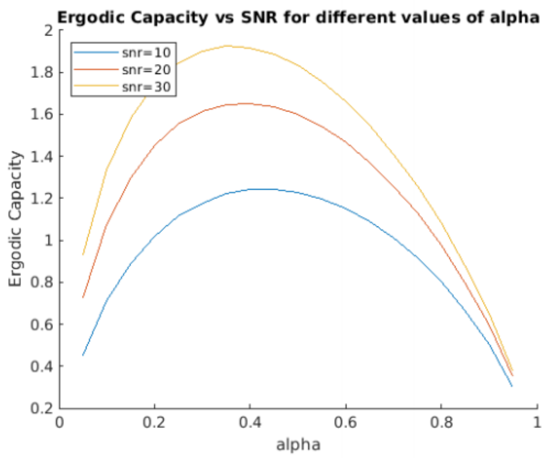

Figure 2.7: Maximum Throughput Vs alpha with respect to ergodic capacity for different values of **SNR**(dB)

2.2 OPTIMUM ALPHA

The optimum alpha for which maximum throughput with respect to ergodic capacity is given by

$$\alpha = \frac{exp(W(\frac{\chi-1}{e})+1)-1}{\chi-1+exp(W(\frac{\chi-1}{e})+1)} \tag{2.34}$$

where

$$\chi = \frac{\eta P_s|h|^2|g|^2}{(\sigma)^2} \tag{2.35}$$

The above equation is obtained by derivating the maximum throughput with respect to ouatage probability and ergodic capacity and equating them to zero.

Plot for optimum alpha vs SNR for various values of eta

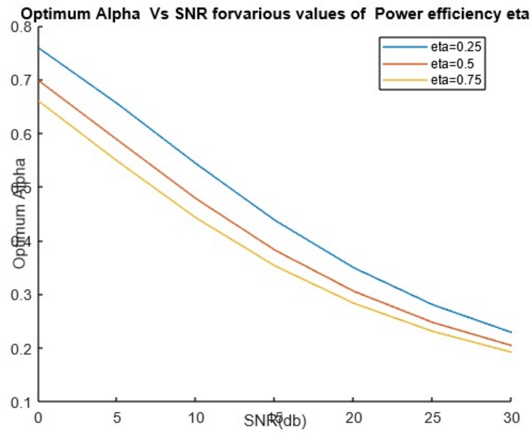

Figure 2.8: Optimum alpha with respect to ergodic capacity

The optimum alpha for which maximum throughput with respect to outage probability can be given by

$$\alpha = \frac{1}{1 + Rln2} \tag{2.36}$$

Where ,R is the Rate of transmission

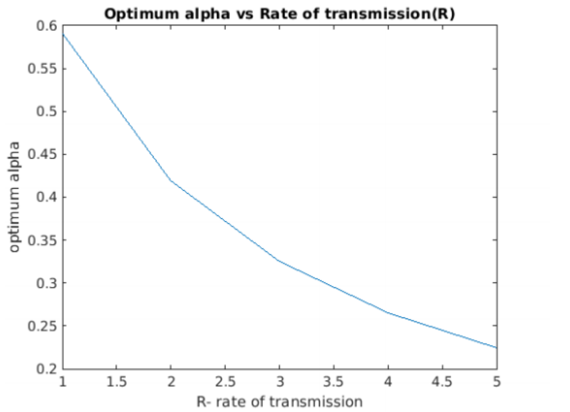

Figure 2.9: Optimum alpha Vs Rate of transmission.

2.3 NAKAGAMI-M DISTRIBUTION

Nakagami fading occurs for multipath scattering with relatively large delay-time spreads, with different clusters of reflected waves.This model was initially proposed for short wave ionospheric propagation.The Nakagami-mi distribution has been given special attention for its ease of manipulation and wide range of applicability .
The parameter m is called the 'shape factor' of the Nakagami or the gamma distribution.

The Rician and the Nakagami model behave **approximately equivalently near their mean value**.

OUTAGE PROBABILITY

Derivation of outage probability for Nakagami-M distribution

Phase-1:WPT

Energy harvested at destination

$$EH = \alpha T \eta P_s |h|^2 \tag{2.37}$$

Phase-2: WIT

Received signal at source

$$Y_s = \sqrt{P_R} g X_e + n_e \tag{2.38}$$

Signal to Noise Ratio is given as

$$\gamma_{DS} = \alpha\eta \frac{P_s |h|^2 |g|^2}{\sigma^2(1-\alpha)} \tag{2.39}$$

$$\gamma_{DS} = \phi |h|^2 |g|^2 \tag{2.40}$$

where

$$\phi = \alpha\eta \frac{P_s}{\sigma^2(1-\alpha)} \tag{2.41}$$

$$P_{OutageDS} = Pr(\gamma_{ds}) < \gamma_{th}) \tag{2.42}$$

$$= Pr(\phi |h|^2 |g|^2 < \gamma_{th}) \tag{2.43}$$

$$= Pr\left(y < \frac{\gamma_{th}}{\phi x}\right) \tag{2.44}$$

where $|h|^2 = x$, $|g|^2 = y$

$$= F_y(\frac{\gamma_{th}}{\phi x}) \tag{2.45}$$

Here The PDF is as follows

$$f_\gamma(\gamma) = \frac{m^m}{(\Omega)^m} \frac{\gamma^{m-1}}{\Gamma(m)} exp(\frac{-m\gamma}{\Omega}) \tag{2.46}$$

The CDF is as follows

$$F_y(\gamma) = \frac{1}{\Gamma(m)} \gamma_{inc}(m, \frac{m}{\Omega}\gamma) \tag{2.47}$$

According to the definition of distribution function
now integrate from zero to infinity

$$P_{Outage_{DS}} = \int_0^\infty {}_{Fy}(\frac{\gamma_{th}}{\phi x}) f_x(x) dx \tag{2.48}$$

$$P_{OutageDS} = \frac{1}{(\Gamma(m))^2} \int_0^\infty \gamma_{inc}(m, \frac{m\gamma_{th}}{\Omega\phi x}) \frac{m^m}{(\Omega)^m} x^{m-1} exp(\frac{-mx}{\Omega}) dx \tag{2.49}$$

let

$$t = \frac{mx}{\Omega} \tag{2.50}$$

$$P_{OutageDS} = \frac{1}{(\Gamma(m))^2} \int_0^\infty \gamma_{inc}(m, \frac{m^2\gamma_{th}}{(\Omega)^2\phi t}) t^{m-1} exp(-t) dt \tag{2.51}$$

let

$$t = \frac{1}{u} \tag{2.52}$$

$$P_{OutageDS} = \frac{1}{(\Gamma(m))^2} \int_0^\infty \gamma_{inc}(m, \frac{m^2\gamma_{th}}{(\Omega)^2\phi} u)(\frac{1}{u})^{m+1} exp(\frac{-1}{u}) du \tag{2.53}$$

we know that

$$exp(\frac{-t}{\gamma}) = G\,{}^{1\,0}_{0\,1}\left({}^{-}_{0} \middle| \frac{t}{\gamma} \right) \tag{2.54}$$

$$exp(\frac{-t}{\gamma}) = G\,{}^{0\,1}_{1\,0}\left({}^{1}_{-} \middle| \frac{\gamma}{t} \right) \tag{2.55}$$

$$P_{OutageDS} = \frac{1}{(\Gamma(m))^2} \int_0^\infty G\,{}^{1\,1}_{1\,2}\left({}^{1}_{m,0} \middle| \frac{m^2\gamma_{th}}{(\Omega)^2\phi} u \right) G\,{}^{0\,1}_{1\,0}\left({}^{1}_{-} | u \right) (\frac{1}{u})^{m+1} du \tag{2.56}$$

By using the properties of integration of product of 2 Meijer G functions we have the resultant outage probability as

$$P_{Outage_{DS}} = G\,{}^{2\,1}_{1\,3}\left({}^{1}_{m,0,m} \middle| \frac{m^2\gamma_{th}}{(\Omega)^2\phi} \right) \tag{2.57}$$

Plots for Outage probability

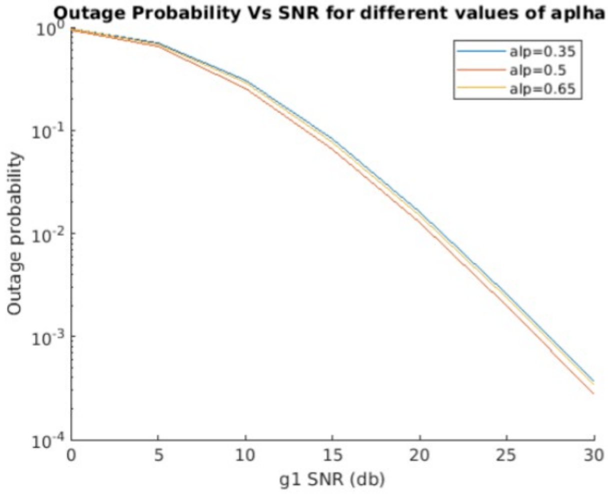

Figure 2.10: Outage Probability Vs SNR

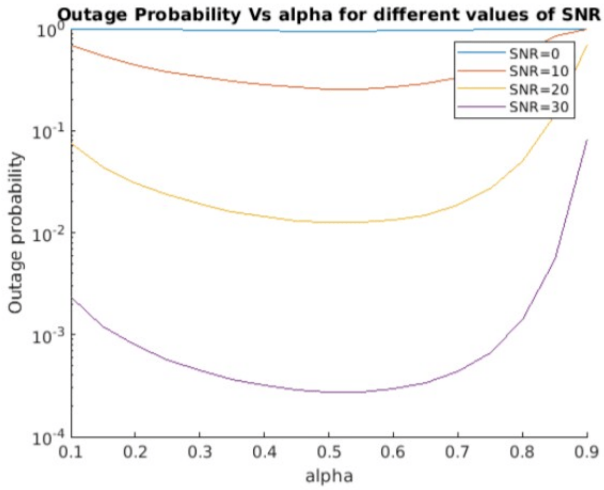

Figure 2.11: Outage Probability Vs alpha

BIT ERROR RATE

BER for a nakagami-m distribution can be given by

$$BER = \frac{a}{2}\sqrt{\frac{b}{\pi}}\int_0^\infty \frac{exp(-b\gamma)}{\sqrt{\gamma}}F(\gamma)d\gamma \tag{2.58}$$

where a,b are modulation coefficients

$$F(\gamma) = G^{\,2\,1}_{\,1\,3}\left({}^{\quad 1}_{m,0,m} \middle| \frac{m^2\gamma}{(\Omega)^2\phi} \right) \tag{2.59}$$

Now converting the the exponential function in BER in terms of Meijer G function we get

$$exp(-b\gamma) = G^{1\,0}_{0\,1}\left({- \atop 0} \middle| b\gamma \right) \tag{2.60}$$

$$BER = \frac{a}{2}\sqrt{\frac{b}{\pi}} \int_0^\infty (\gamma)^{-0.5} G^{1\,0}_{0\,1}\left({- \atop 0} \middle| b\gamma \right) G^{2\,1}_{1\,3}\left({1 \atop m,0,m} \middle| \frac{m^2\gamma}{(\Omega)^2\phi} \right) d\gamma \tag{2.61}$$

From the properties of Meijer g function from wolfram alpha

We have the resultant BER as follows

$$BER = z\frac{a}{2\sqrt{\pi}} G^{2\,2}_{2\,3}\left({1,0.5 \atop m,0,m} \middle| \frac{m^2}{\phi\Omega b} \right) \tag{2.62}$$

Plot for Bit Error Rate(BER)

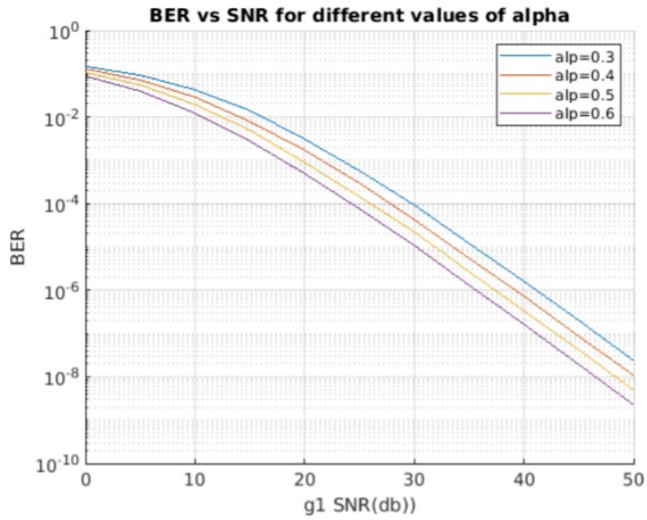

Figure 2.12: BER Vs SNR for different values of alpha

ERGODIC CAPACITY

Ergodic capacity represents the effective rate of the system that can be achieved with small error probability.It can be calculated by averaging instantaneous capacity across all fading states.

$$C_{erg} = E[log_2(1+\gamma)] \tag{2.63}$$

$$C_{erg} = \frac{1}{ln2} \int_0^\infty f_\gamma(\gamma) ln(1+\gamma) d\gamma \tag{2.64}$$

We know that PDF of the received SNR gamma,can be found by derivative of outage probability which is nothing but the CDF of gamma

$$f_\gamma(\gamma) = \frac{m^2}{(\Omega)^2\phi} G^{2\,2}_{2\,4}\left({}^{-1,0}_{m-1,-1,m-1,0} \middle| \frac{m^2\gamma}{(\Omega)^2\phi} \right) \tag{2.65}$$

Now we convert the logarithmic function present in the above equation in merjer G function as follows

$$ln(1+\gamma) = G^{1\,2}_{2\,2}\left({}^{1,1}_{1,0} \middle| \gamma \right) \tag{2.66}$$

Now by substituting the above expression in the capacity function

$$C_{erg} = \frac{1}{ln(2)} \frac{m^2}{(\Omega)^2\phi} \int_0^\infty G^{2\,2}_{2\,4}\left({}^{-1,0}_{m-1,-1,m-1,0} \middle| \frac{m^2\gamma}{(\Omega)^2\phi} \right) * G^{1\,2}_{2\,2}\left({}^{1,1}_{1,0} \middle| \gamma \right) d\gamma \tag{2.67}$$

By using the properties of integration of product of 2 Meijer G functions we have the resultant ergodic capacity as follows

$$\implies C_{erg} = \frac{1}{ln(2)} G^{3\,4}_{6\,4}\left({}^{1,1,1-m,1,1-m,0}_{1,1,1,0} \middle| \frac{(\Omega)^2\phi}{m^2} \right) \tag{2.68}$$

Plot for Ergodic Capacity

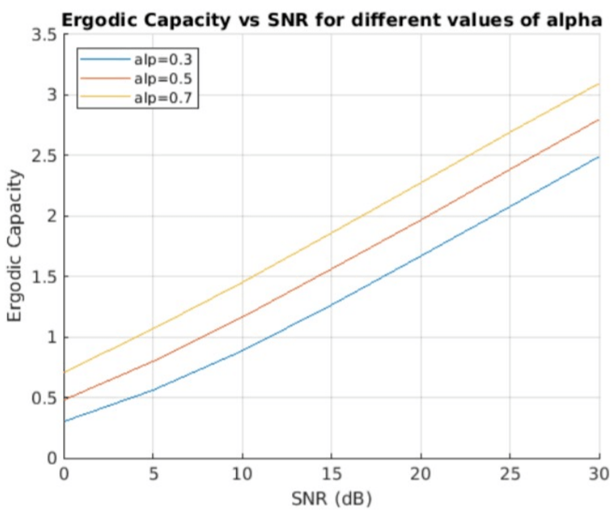

Figure 2.13: Ergodic Capacity Vs SNR for different values of alpha

THROUGHPUT

The expression for maximum throughput with respect to outage probability for nakagami-m distribution is as follows

$$Throughput = 1 - G^{2\,1}_{1\,3}\left({}^{1}_{m,0,m} \middle| \frac{m^2\gamma_{th}}{(\Omega)^2\phi} \right) \tag{2.69}$$

Plots for Maximum Throughput

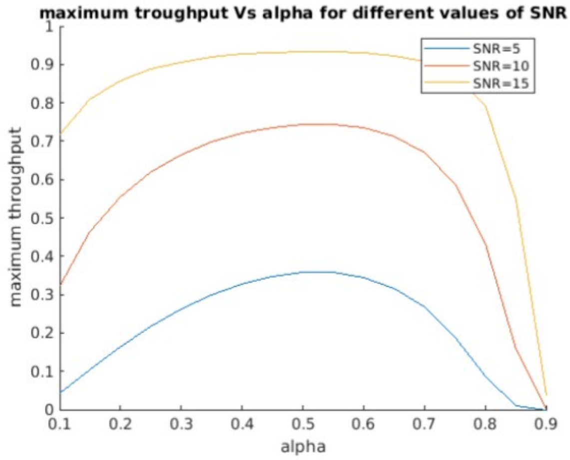

Figure 2.14: Maximum throughput Vs alpha for different values of SNR

2.4 RAYLEIGH DISTRIBUTION

Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.
The Rayleigh fading model is ideally suited to situations where there are large numbers of signal paths and reflections. Typical scenarios include cellular telecommunications where there are large number of reflections from buildings and the like and also HF ionospheric communications where the uneven nature of the ionosphere means that the overall signal can arrive having taken many different paths.

OUTAGE PROBABILITY

The PDF for Rayleigh distribution is as follows

$$f_\gamma(\gamma) = \frac{1}{(k)} exp(\frac{-\gamma}{k}) \tag{2.70}$$

And the CDF is as follows

$$F_y(\gamma) = 1 - exp(\frac{-\gamma}{k}) \tag{2.71}$$

According to the definition of distribution function now integrate from zero to infinity

$$P_{OutageDS} = \int_0^\infty {}_{Fy}(\frac{\gamma_{th}}{\phi x}) f_x(x) dx \tag{2.72}$$

$$P_{OutageDS} = \int_0^{\infty} [1 - exp(\frac{-\gamma_{th}}{\phi x k})] \frac{1}{(k)} exp(\frac{-x}{k}) dx \tag{2.73}$$

let

$$P_{OutageDS} = I_0 - I_1 \tag{2.74}$$

we have

$$I_0 = 1 \tag{2.75}$$

and

$$I_1 = \frac{1}{k} \int_0^{\infty} exp(\frac{-\gamma_{th}}{\phi x k}) exp(\frac{-x}{k}) dx \tag{2.76}$$

We can get the above equation in terms of meijer G function as follows

$$I_1 = \frac{1}{k} \int_0^{\infty} G_{1\,0}^{0\,1} \left({}^{1}_{-} \middle| \frac{\phi k x}{\gamma_{th}} \right) G_{0\,1}^{1\,0} \left({}^{-}_{0} \middle| \frac{x}{k} \right) dx \tag{2.77}$$

By using the properties of integration of product of 2 Meijer G functions we have the resultant outage probability as

$$P_{Outage_{DS}} = 1 - \frac{1}{k} G_{2\,0}^{0\,2} \left({}^{1}_{-} \middle| \frac{\phi k^2}{\gamma_{th}} \right) \tag{2.78}$$

Plots for Outage probability

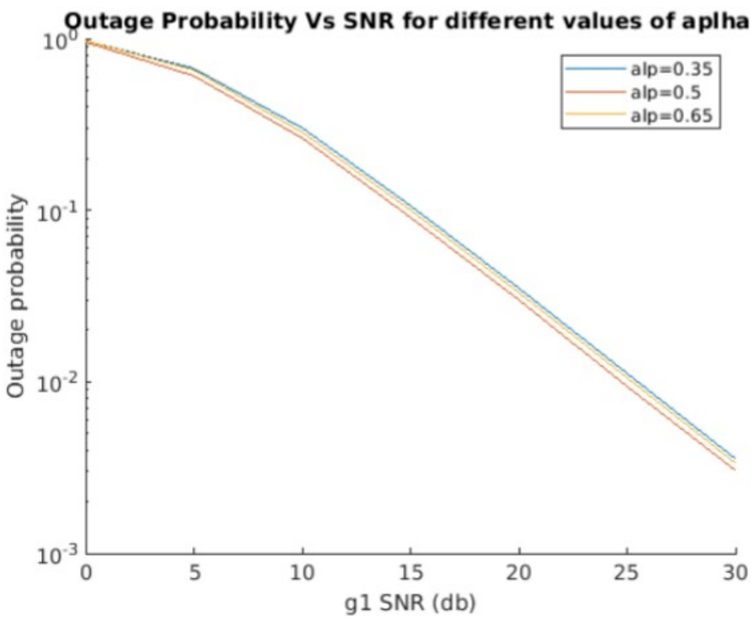

Figure 2.15: Outage Probability Vs SNR

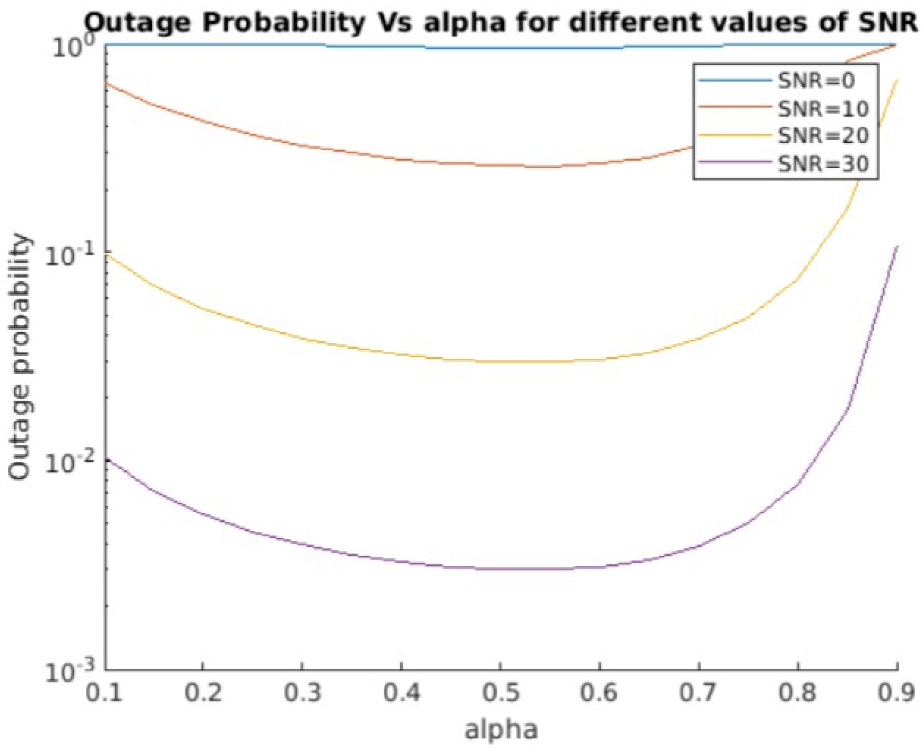

Figure 2.16: Outage Probability Vs alpha

BIT ERROR RATE

BER for a rayleigh distribution can be given by

$$BER = \frac{a}{2}\sqrt{\frac{b}{\pi}}\int_{0}^{\infty}\frac{exp(-b\gamma)}{\sqrt{\gamma}}F(\gamma)d\gamma \tag{2.79}$$

where a,b are modulation coefficients

$$F(\gamma) = 1 - \frac{1}{k}G_{2\,0}^{0\,2}\left(\begin{smallmatrix}1\\-\end{smallmatrix}\middle|\frac{\phi k^2}{\gamma}\right) \tag{2.80}$$

We have the final expression of BER as follows

$$BER = \frac{a}{2}\sqrt{\frac{1}{\pi}}G_{2\,3}^{2\,2}\left(\begin{smallmatrix}1,0.5\\1,1,0\end{smallmatrix}\middle|\frac{a_{ds}a_{sd}}{\phi b}\right) \tag{2.81}$$

Plots for Bit Error Rate(BER)

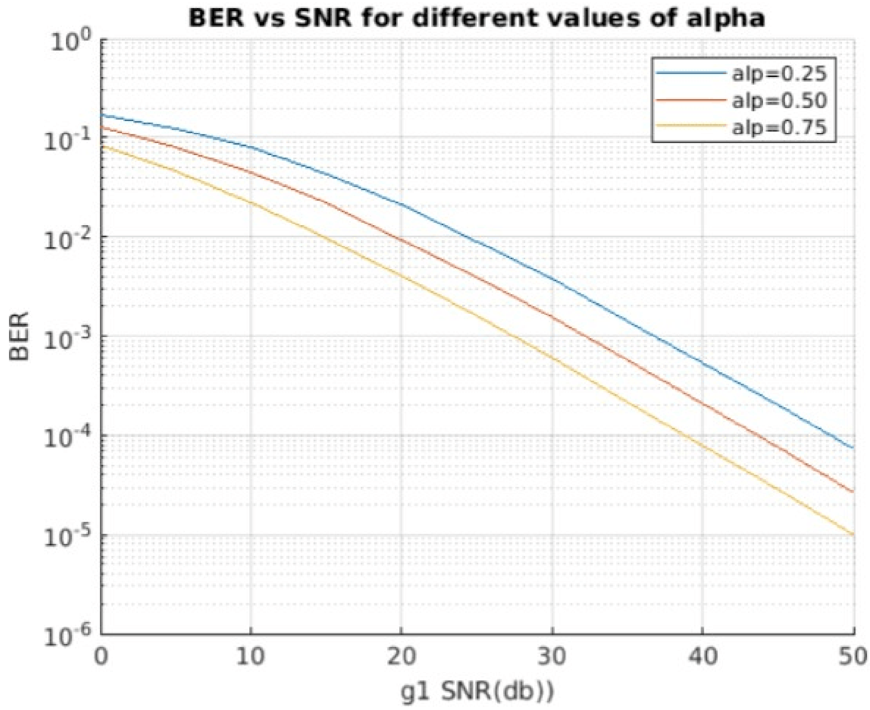

Figure 2.17: BER Vs SNR for different values of alpha

ERGODIC CAPACITY

$$C_{erg} = E[log_2(1+\gamma)] \tag{2.82}$$

$$C_{erg} = \frac{1}{ln2}\int_0^{\infty} f_\gamma(\gamma) ln(1+\gamma) d\gamma \tag{2.83}$$

The final expression for ergodic capacity is as follows

$$C_{erg} = \frac{1}{ln(2)} G\,_{6\ 4}^{3\ 4}\left({}^{1,0,0,1,0,1}_{\ \ 1,1,0,0} \middle| \frac{\phi}{a_{ds}a_{sd}} \right) \tag{2.84}$$

Plots for Ergodic Capacity

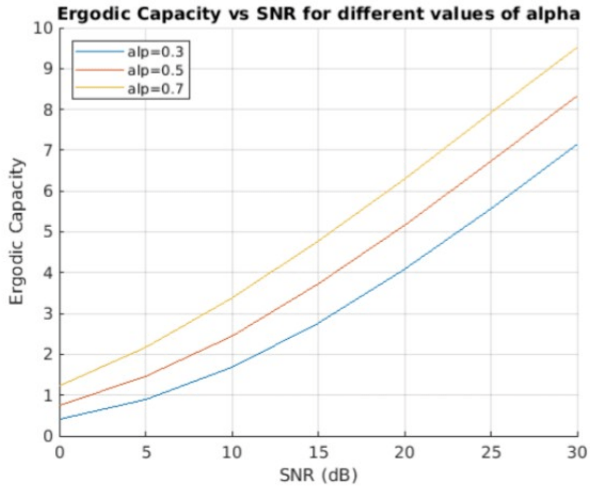

Figure 2.18: Ergodic Capacity Vs SNR for different values of alpha

THROUGHPUT

The expression for maximum throughput with respect to outage probability for rayleigh distribution is as follows

$$Throughput = \frac{1}{k} G^{\,0\,2}_{\,2\,0} \left(\begin{matrix} 1 \\ - \end{matrix} \middle| \frac{\phi k^2}{\gamma_{th}} \right) \tag{2.85}$$

Plots for Maximum Throughput

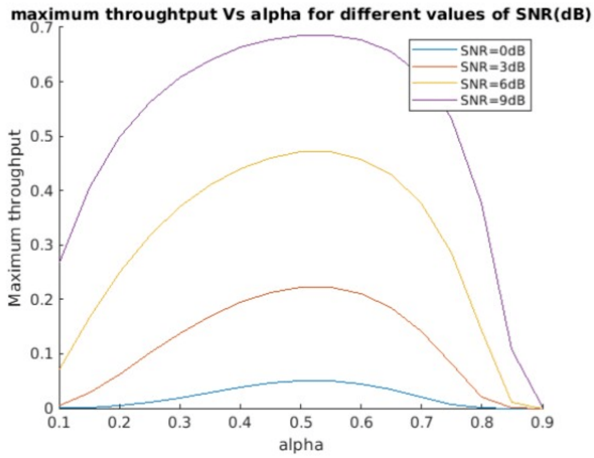

Figure 2.19: Maximum throughput Vs alpha for different values of SNR

2.5 WEIBULL DISTRIBUTION

The fading model for the Weibull distribution considers amultipath wave propagating in a non-homogeneous environment. At a given point the received signal encompasses a multipath component and the propagation environment is such that the resulting signal is observed as a non-linear function of the modulus of this component.

OUTAGE PROBABILITY

The PDF for weibull distribution is as follows

$$f_\gamma(\gamma) = \frac{\beta}{k}(\gamma)^{\beta-1}exp(\frac{-(\gamma)^\beta}{k}) \tag{2.86}$$

The CDF is as follows

$$F_y(\gamma) = 1 - exp(\frac{-(\gamma)^\beta}{k} \tag{2.87}$$

According to the definition of distribution function
now integrate from zero to infinity

$$P_{OutageDS} = \int_0^\infty {}_{Fy}(\frac{\gamma_{th}}{\phi x})f_x(x)dx \tag{2.88}$$

$$P_{OutageDS} = \int_0^\infty [1 - exp(\frac{-(\gamma_{th})^\beta}{(\phi x)^\beta k})]\frac{\beta}{k}(x)^{\beta-1}exp(\frac{-(x)^\beta}{k})dx \tag{2.89}$$

let

$$P_{OutageDS} = I_0 - I_1 \tag{2.90}$$

we have

$$I_0 = 1 \tag{2.91}$$

and let

$$t = x^\beta \tag{2.92}$$

then we have as follows

$$I_1 = \int_0^\infty exp(\frac{-(\gamma_{th})^\beta}{(\phi t)^\beta k})exp(\frac{-t}{k})dt \tag{2.93}$$

Now by converting exponential function to meijer g function and By using the properties of integration of product of 2 Meijer G functions we

$$I_1 = \frac{(\gamma_{th})^\beta k}{(\phi)^\beta} G^{2\,0}_{0\,2}\left({}^{-}_{0,-1} \middle| \frac{(\gamma_{th})^\beta}{(\phi)^\beta} \right) \tag{2.94}$$

$$P_{OutageDS} = 1 - \frac{(\gamma_{th})^\beta k}{(\phi)^\beta} G^{2\,0}_{0\,2}\left({}^{-}_{0,-1} \middle| \frac{(\gamma_{th})^\beta}{(\phi)^\beta} \right) \tag{2.95}$$

Plots for Outage probability

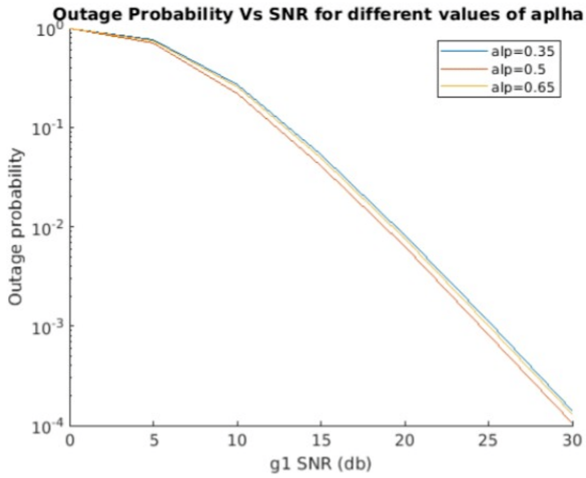

Figure 2.20: Outage Probability Vs SNR

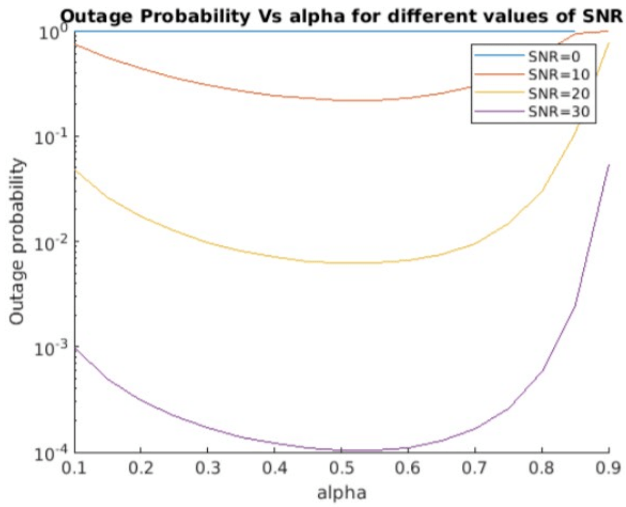

Figure 2.21: Outage Probability Vs alpha

2.6 KAPPA MU DISTRIBUTION

Kappa -mu model is used as a more generalized physical fading model and to describe the describe, parameterize, and fully characterize the corresponding signal in terms of measurable physical parameters , the distribution model.
The K- distribution is a general fading distribution that can be used to represent the small-scale variation of the fading signal in a line-of-sight condition.
K is defined as the ratio between the total power of the dominant components and the total power of the scattered waves.

The K- distribution includes the Rician and the Nakagami-m distributions as special cases.

$$Rayleigh(\kappa = 0, \mu = 1), \tag{2.96}$$

$$Nakagami - m(\kappa = 0, \mu = m), \tag{2.97}$$

$$Rician(\kappa = K, \mu = 1) \tag{2.98}$$

Outage Probability

The outage probability for this distribution is as follows

$$P_{Outage} = \frac{1}{\zeta} \sum_{n=0}^{\infty} \sum_{m=0}^{\infty} C_{m,n} G_{1\ 3}^{2\ 1} \left({}_{n+\mu_h, m+\mu_g, 0}^{1} \middle| \frac{\gamma_{th} a_g a_h}{\phi} \right) \tag{2.99}$$

where

$$C_{m,n} = \frac{(\mu_h \kappa_h)^n (\mu_g \kappa_g)^m}{m! n! \Gamma(n + \mu_h) \Gamma(m + \mu_g)} \tag{2.100}$$

$$\zeta = exp(\mu_h \kappa_h + \mu_g \kappa_g) \tag{2.101}$$

Bit Error Rate

The expression for the bit error rate is as follows

$$P_{ber} = \frac{1}{2\zeta\Gamma(a)} \sum_{n=0}^{\infty} \sum_{m=0}^{\infty} C_{m,n} G_{5\ 4}^{4\ 2} \left({}_{0,a,1,0}^{1-n-\mu_h, 1-m-\mu_g, 1, 0, 1} \middle| \frac{\phi b}{a_g a_h} \right) \tag{2.102}$$

Ergodic Capacity

The expression for ergodic capacity is as follows

$$C_{erg} = \frac{1}{ln(2)\zeta} \sum_{n=0}^{\infty} \sum_{m=0}^{\infty} C_{m,n} G_{6\ 4}^{3\ 4} \left({}_{1,1,0,0}^{1,1-n-\mu_h, 1-m-\mu_g, 1, 0, 1} \middle| \frac{\phi}{a_g a_h} \right) \tag{2.103}$$

CHAPTER 3

COMPARATIVE ANALYSIS

1)Plot of Outage Probability Vs SNR for various fading channels

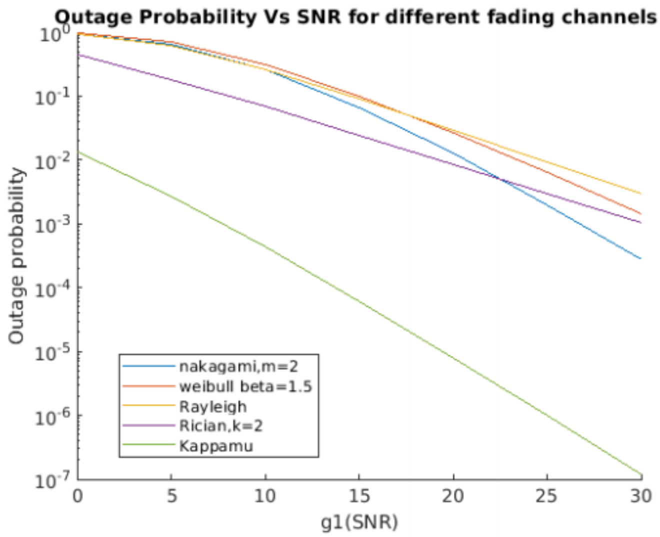

Figure 3.1: outage probability Vs SNR for various fading channels

2)Plot of Bit Error Rate Vs SNR for various fading channels

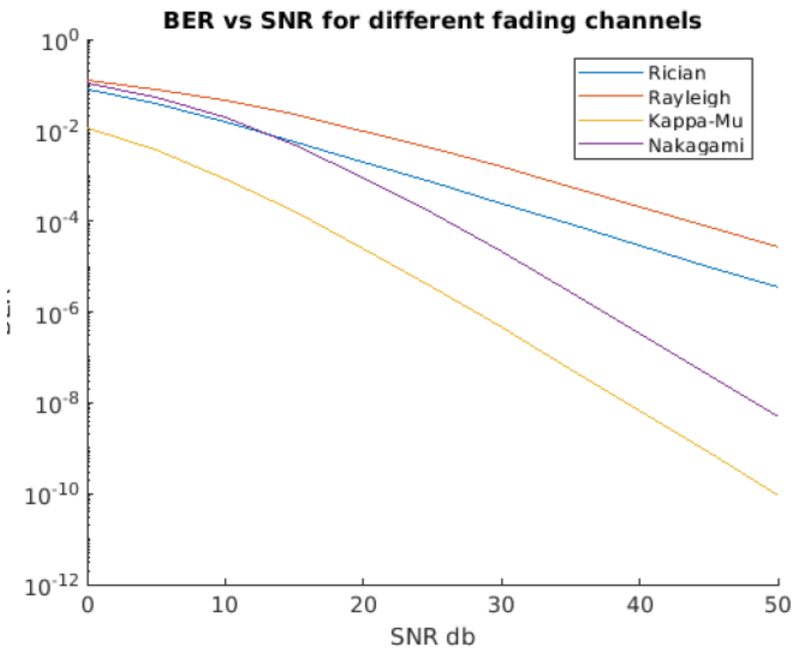

Figure 3.2: Bit Error Rate Vs SNR for various fading channels

3)Plot of Ergodic Capacity Vs SNR for various fading channels

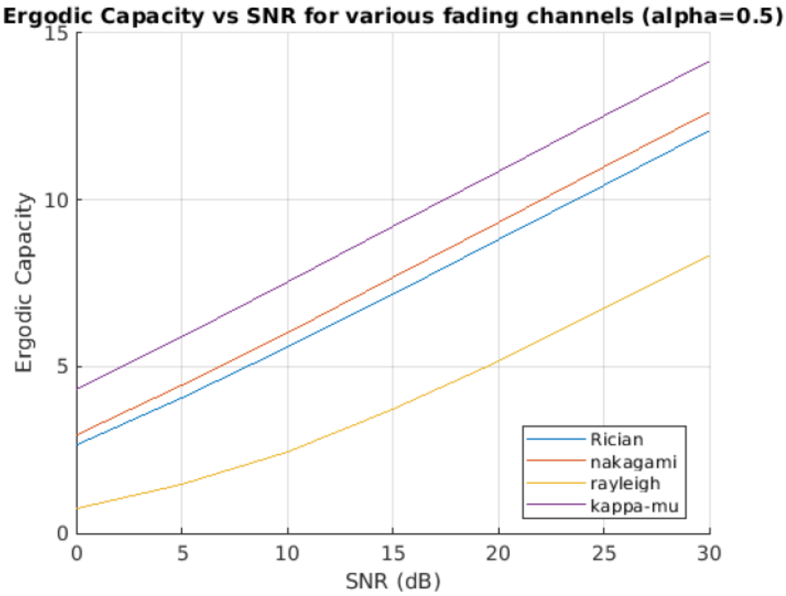

Figure 3.3: Ergodic Capacity Vs SNR for various fading channels

4)Plot of Maximum Throughput with respect to ergodic capacity Vs alpha for various fading channels

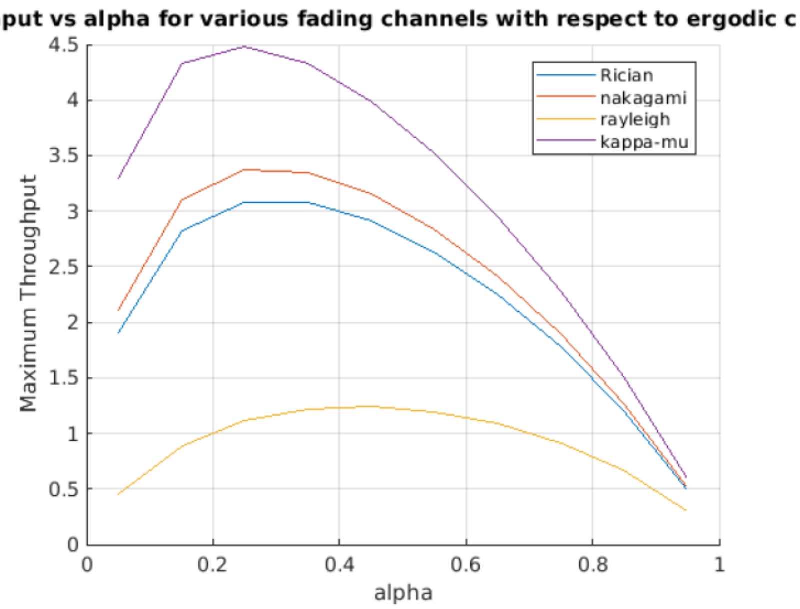

Figure 3.4: Maximum Throughput with respect to ergodic capacity Vs alpha for various fading channels

5)Plot of Maximum Throughput with respect to outage probability Vs alpha for various fading channels

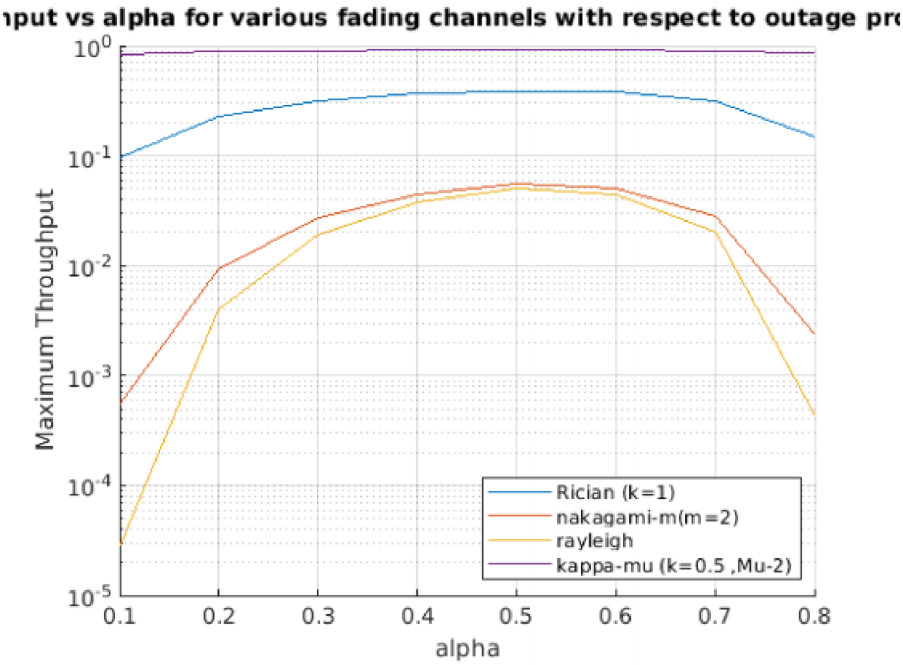

Figure 3.5: Maximum Throughput with respect to outage probability Vs alpha for various fading channels

OBSERVATIONS AND CONCLUSIONS

As we can see from plots of SNR vs Outage probability for our model , Outage probability is better(lesser) for alpha=0.5 for the same range of SNR.From this we can conclude if the time-splitting coefficient is around 0.59 , the outage probability is least and throughput will be maximum. From plots of SNR vs BER for various values of alpha we can observe that BER is decreasing with increasing value alpha for the same range of SNR , from which we can conclude that if time-splitting coefficient is more , then BER will less.

From plots of SNR vs Ergodic Capacity for various K(rician factor) values , as K increases , the ergodic capacity is increasing for same range of SNR.From simulations of SNR vs Ergodic Capacity for various alpha(time-splitting constant) values , as alpha increases the ergodic capacity increases for same range of SNR.

From the graph of maximum throughput Vs alpha, we observe that that max throughput is attained at value of alpha close to 0.59 when Rate of transmission is 1. When we observe max throughput Vs alpha with respect to ergodic capacity, the range of values of alpha for which max throughput obtained is changes gradually from 0.4 to 0.55 as SNR values varies from 10 to 20 to 30.

Likewise, when we observe the plot for optimum alpha vs SNR for various values of power efficiency(eta), the optimum value of alpha decreases as SNR increases. Also we can observe that lowering of optimum value of alpha as eta increases.

From Optimum alpha vs Rate of Transmission we can observe that optimum alpha decreases as Rate of transmission increase. This can be viewed as consequence of threshold SNR being a function of Rate of Transmission and alpha (time-splitting factor).

When comparing Outage Probability vs SNR for alpha=0.5 for various fading channels, except for kappa-mu, **Rician channel** has **least** outage Probability till SNR reaches 20 db,i.e performs better than other channels even for lower values of SNR.

The BER vs SNR for alpha=0.5 comparison leads to a conclusion that , Rician channel has lesser BER than other channels except for kappa-mu at smaller ranges of SNR.So we can tell that it performs better with low BER at noisy environment better than other channels.This can be observed from the other comparisons of Maximum Throughput at lower SNR values.

From the above observations we can conclude that Rician Distribution is most preferable because of better performance at low SNR values in terms of lesser outage , lesser BER and maximum through-puts.

FUTURE WORKS

- This study can be further extended for non linear Energy harvesting techniques as they are more suitable for practical uses than the linear harvesting method used in this analysis.
- Also, include Non-orthogonal Multiple access methodology to be considered in the system in order to feal with near-far problem.
- This analysis can be further extended to Kappa-mu shadowed model.

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